On the Inclinations of the Planes of some Spiral Nebulæ to the Galaxy. By H. Knox Shaw, B.A.

1. The measurements of spiral nebulæ contained in this paper were made at the suggestion of Professor Turner to test whether there is any connection between the planes of these nebulæ and that of the Milky Way, as seems to be the case with binaries and long-period variables (see *M.N.*, lxvii. p. 498 *seq.*, p. 352). The general assumption is made that each nebula is circular in form and appears elliptical owing to the inclination of its plane to the line of sight. This inclination is determined by measuring the axes of the ellipse which the nebula presents to us. It is of course impossible to tell in which direction the plane is tilted, and thus two poles are found for each nebula, either of which is equally likely to be the true one. They are each at a distance γ (measured in arc) from the nebula in the direction perpendicular to the major axis of the ellipse, where $\sec\gamma = \frac{a}{b}$; a, b being the measured major and minor axes of the ellipse.

2. Measurements were made of twenty-five spiral nebulæ from Isaac Roberts' photographs. Those most open, *i.e.* most circular in form, were excluded, for two reasons: firstly, because it was impossible to orientate them with any degree of certainty; and secondly, because a small error in the ratio of the axes, when they are nearly equal, produces a large error in γ. To avoid the labour of some rather heavy computation, the positions of the two ambiguous poles were found by means of a globe and protractor. This method seemed accurate enough for the purpose, as the photographs naturally did not admit of very precise measurement, the outline of the nebula being often very ill-defined, and dependent upon personal opinion. Two independent determinations were therefore made, at an interval of about a fortnight, in order that the second should not be in any way influenced by the first. It will be seen that in the case of some nebulæ the opinion as to their form changed considerably during the interval. The two determinations are throughout the paper shown bracketed, and in discussing the results the means of the two determinations are used.

3. In Table I. the measurements of the photographs will be found. The first column gives the name of the nebula, the second and third its R.A. and declination, the fourth its galactic latitude, the fifth and sixth the axes of the ellipse, the seventh the arc γ, and the eighth the angle θ, this being the inclination of the major axis to the hour circle, considered positive when the south end is turned in the direction of increasing R.A.

TABLE I.

Measurements of the Nebulæ.

Nebula.	R.A. h	R.A. m	Dec. °	Gal. Lat. °	*a.* in.	*b.* in.	*γ.* °	*θ.* °
M 31	0	37	+41	−22	6·20	1·50	76	−35
					6·30	1·40	77	−34
M 33	1	28	+30	−31	1·50	1·30	30	−43
					3·10	1·50	61	−14
H V. 19	2	16	+42	−17	0·97	0·11	83	−20
					0·98	0·13	82	−20
H V. 44	7	27	+66	+30	0·90	0·55	52	+58
					1·10	0·80	44	+53
H I. 56	9	27	+22	+46	0·60	0·35	54	−12
					0·60	0·28	62	−11
H I. 285	9	39	+68	+41	0·61	0·21	70	+38
					0·66	0·25	68	+38
M 81	9	47	+70	+41	1·30	0·70	58	+36
					1·30	0·75	55	+35
H V. 47	9	55	+56	+48	0·90	0·15	80	+19
					0·90	0·12	82	+21
H I. 199	10	14	+46	+55	1·10	0·32	72	−40
					1·20	0·34	74	−38
H V. 46	11	6	+56	+56	1·10	0·25	77	−81
					1·10	0·20	80	−83
M 65	11	14	+14	+66	1·16	0·30	75	+ 7
					1·25	0·40	74	+ 7
M 66	11	15	+14	+66	1·05	0·40	68	+ 2
					1·20	0·65	71	+ 2
H II. 730	11	28	+48	+65	0·91	0·63	46	−12
					0·94	0·65	46	−14
H IV. 56	11	58	+45	+70	0·60	0·25	65	+46
					0·60	0·35	54	+60
H I. 206	12	0	+51	+65	0·88	0·28	71	−45
					0·91	0·20	77	−45
H V. 41	12	12	+38	+78	2·30	0·20	85	−46
					2·30	0·20	85	−45
M 99	12	14	+15	+76	0·65	0·52	37	−31
					0·60	0·50	34	−36
H V. 2	12	29	+ 3	+64	1·35	0·40	73	+55
					1·15	0·45	67	+55

TABLE I.—*continued.*

Nebula.	R.A.		Dec.	Gal. Lat.	*a.*	*b.*	γ.	θ.
	h	m	°	°	in.	in.	°	°
H I. 92	12	31	+28	+87	0·70	0·26	69	+40
					0·70	0·28	66	+40
H V. 24	12	31	+27	+87	2·80	0·22	86	+47
					2·70	0·20	86	+48
H V. 42	12	37	+33	+84	2·10	0·25	83	−84
					2·15	0·22	84	−80
H I. 84	12	46	+26	+88	0·90	0·50	56	−42
					1·15	0·80	46	−42
M 64	12	52	+22	+84	1·30	0·60	63	+75
					1·20	0·55	63	+71
M 63	13	11	+43	+73	1·20	0·60	60	+86
					1·20	0·65	57	+86
H IV. 76	20	33	+60	+11	0·70	0·50	44	−24
					1·00	0·60	53	−39

4. The second and third columns of Table II. give the R.A. and declination of one pole of the nebula, and the fourth column the corresponding galactic latitude (Γ), the fifth, sixth, and seventh giving the similar quantities for the alternative pole. Γ′ is in each case the smaller of the galactic latitudes. The galactic longitudes of the poles were also calculated, to see whether there was any sign of clustering in longitude. As no such clustering was apparent, it seemed unnecessary to include them in the table.

TABLE II.

Positions of the Poles of the Nebulæ.

Nebula.	R.A.		Dec.	Γ.	R.A.		Dec.	Γ′.
	h	m	°	°	h	m	°	°
M 31	17	56	+34	+24	3	56	−22	−46
	17	12	+41	+34	4	20	−16	−39
M 33	23	16	+48	−12	2	56	+ 8	−42
	20	20	+33	− 3	5	24	+ 3	−16
H V. 19	7	20	− 7	+ 5	19	4	+27	+ 7
	6	56	−10	− 1	19	16	+28	+ 3
H V. 44	6	4	+17	0	17	28	+63	+33
	5	54	+25	0	15	36	+63	+44
H I. 56	5	28	+26	− 3	13	0	+ 4	+66
	5	0	+25	− 9	13	36	+ 2	+60
H I. 285	6	28	+ 6	0	17	44	+33	+25
	6	12	+ 9	− 2	17	40	+34	+27

TABLE II.—*continued.*

Nebula.	R.A. h	R.A. m	Dec. °	Γ. °	R.A. h	R.A. m	Dec. °	Γ′. °
M 81	6	36	+19	+8	17	36	+43	+30
	6	40	+23	+10	17	32	+45	+31
H V. 47	4	52	+2	−23	17	8	+24	+30
	5	56	−1	−11	18	0	+26	+20
H I. 199	2	44	+44	−13	13	36	−12	+48
	2	44	+42	−15	13	48	−11	+48
H V. 46	23	40	+46	−15	11	44	−20	+41
	23	8	+44	−15	11	28	−24	+35
M 65	6	30	−5	−5	16	18	+6	+34
	6	20	+2	−4	16	20	+14	+38
M 66	6	36	+4	+1	15	52	+7	+41
	6	24	+7	−1	16	4	+8	+38
H II. 730	7	4	+38	+21	14	52	+24	+61
	6	52	+43	+20	15	0	+25	+59
H IV. 56	19	4	+49	+16	9	20	−11	+28
	19	0	+67	+23	10	28	−5	+44
H I. 206	3	52	+47	−4	15	4	−8	+40
	3	24	+42	−11	15	12	−15	+34
H V. 41	3	8	+37	−12	15	12	−19	+31
	3	40	+43	−8	16	0	−28	+17
M 99	14	22	−5	+49	9	48	+32	+52
	14	8	−5	+51	10	4	+33	+56
H V. 2	8	32	−50	−5	16	52	+54	+37
	8	44	−42	+2	16	8	+52	+45
H I. 92	18	32	+49	+22	9	56	16	+31
	18	12	+57	+26	9	8	−15	+23
H V. 24	20	20	+37	−1	8	8	−34	+1
	20	24	+45	+3	8	20	−37	+1
H V. 42	0	36	+63	0	13	32	−50	+12
	0	52	+62	−1	13	28	−51	+11
H I. 84	15	24	−13	+33	8	12	+52	+35
	15	4	−7	+41	9	8	+48	+44
M 64	11	0	−39	+20	16	16	+78	+34
	11	28	−39	+21	17	20	+74	+32
M 63	1	20	+77	+14	12	48	−17	+45
	1	12	+80	+17	13	0	−15	+47
H IV. 76	23	36	+27	−33	15	16	+55	+51
	22	36	+14	−38	12	28	+54	+62

5. A rough inspection of Table II. will show that, with few exceptions, one of the ambiguous poles is quite near the galaxy. It will be instructive to compare the distribution of these poles with what might be called a chance distribution. Now, in the first place, let the general assumption be made that the nebulæ are distributed uniformly in galactic latitude, and that their planes are inclined at every sort of angle to the line of sight, *i.e.* that the values of γ are distributed uniformly between $0°$ and $90°$, and values of θ uniformly between $-90°$ and $+90°$. Then the chance that any single pole shall lie between galactic latitudes 0 and α is $\sin \alpha$. Hence the chance that at least one of a pair of poles shall be within a distance α of the galaxy is $1-(1-\sin\alpha)^2$ or $2\sin\alpha-\sin^2\alpha$. From this are derived the numbers in the third column of Table III., while the second column gives the corresponding numbers derived from the figures in the column of Table II. headed Γ; the fourth column shows the excess of the observed over the calculated. It will be noticed that there is a decided excess of poles within ten degrees of the galaxy.

TABLE III.

Distribution of Poles.

Gal. Lat.	O.	C.	O–C.
0°–10°	13	8	+5
10–20	5	6	–1
20–30	4	5	–1
30–40	2	3	–1
40–50	1	2	–1
50–90	0	1	–1

6. We have seen that, on the assumption of a uniform distribution of the nebulæ with regard to the galactic plane and also of their orientations, there are more poles near the galaxy than can be accounted for by the theory of probability. We must now consider how far these assumptions of uniformity are true with regard to the twenty-five nebulæ under discussion. The distribution of the nebulæ with regard to the galactic plane is best seen by reference to Table IV., where the second column gives the number of nebulæ in the various galactic zones, the third the number there would be in each zone were the distribution uniform, and the fourth the excess of the former over the latter. It will at once be seen that the nebulæ are by no means distributed uniformly, there being no less than fourteen within 30° of the galactic pole.

TABLE IV.

Distribution of Nebulæ.

Gal. Lat.	O.	C.	O–C.
0°–40°	5	16	−11
40–50	4	3	+1
50–60	2	3	−1
60–70	5	2	+3
70–80	4	1	+3
80–90	5	0	+5

7. Table V. has been formed to show in a similar way the distribution of the values of γ. Inspection of the table will show that half of the nebulæ have a value of γ greater than 70°.

TABLE V.

Distribution of Values of γ.

Values of γ.	Number.
0°–30°	0
30–40	1
40–50	4
50–60	4
60–70	4
70–80	7
80–90	5

8. Thus, so far from the nebulæ being placed and orientated uniformly, they show a decided tendency to cluster near the galactic pole, fourteen of them being within 30 degrees of it; and the values of γ are large, twelve being greater than 70 degrees. The absence of small values of γ is due to the fact that the more open nebulæ were not measured, for the reasons given above. The combination of these two properties (as shown by Tables IV. and V.) accounts for a great number of the small galactic latitudes of the poles. Thus it is difficult to decide whether the clustering of the poles near the galaxy may not be due to the fact that the majority of the nebulæ lie near the galactic pole, and are tilted at a considerable angle to the line of sight. The fact that the galactic latitudes of five nebulæ which were considered to be too open to admit of measurement—and would thus have small values of γ—range from 45 to 78 degrees, shows that, could these nebulæ have been included in the determination, their poles would have been found to lie in large galactic latitudes. It seems clear that more evidence is required before any definite opinion can be advanced as to whether there is any real clustering of the poles near the galaxy. At present I do not think that anything more can be said than that the result of the investigation has been positive rather than negative, and consequently that it will be well worth continuing it by measuring all available photographs of spiral nebulæ.

The Short Period Variable W Ursæ Majoris.

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Observations of W Ursæ Majoris (B.D. + 56°, 1400, $\alpha = 9^h\ 36^m\ 44^s$, $\delta = 56°\ 24'{\cdot}6$, 1900), with the photometer D attached to the Steinheil refractor of the Potsdam Astrophysical Observatory, have been made by me during the last year as often as opportunity offered. This interesting variable, with a period of only four hours, was discovered by Müller and Kempf at Potsdam, and these observers have already published a light curve and ephemeris,* but it seemed desirable to have additional data for the light curve, and also of interest to observe some additional minima. In all, 263 observations were made, in each case the comparison star used being B.D. + 54°, 1329 ($\alpha = 9^h\ 41^m\ 44^s$, $\delta = 54°\ 43'{\cdot}7$, 1900), the magnitude of which from the Potsdam *Durchmusterung* observations is 7·73. As usual, each observation consisted of four settings for the variable star and four for the comparison star in alternate observations, the variable being observed before and after the comparison star.

In Table I. the complete observations are given, the columns containing successively the date and Potsdam sidereal time of observation, Greenwich mean time (with reduction to Sun applied), and the observed magnitude (corrected for atmospheric absorption). The remaining columns contain elements computed as explained later.

Table I.

Date.	Sid. Time.	G.M.T.	Mag.	C.	O—C.	Prec. Min.	Epoch.
1907.	h m	h m				h m	
May 29	13 54	8 33	8·08	8·16	−·08	7 53	9568
	14 11	50	7·86	8·05	−·19		
	18	57	7·95	8·03	−·08		
	33	9 12	8·09	7·99	+·10		
	15 10	49	8·02	7·91	+·11		
	22	10 1	7·85	7·90	−·05		
	27	6	7·86	7·90	−·04		
	43	22	7·81	7·91	−·10		
	53	32	7·77	7·93	−·16		
June 5	14 22	8 33	8·51	8·27	+·24	8 2	9610
	37	48	7·92	8·11	−·19		
	47	58	7·97	8·05	−·08		
	15 7	9 18	8·11	8·00	+·11		
	16	27	7·98	7·98	·00		
	30	41	7·88	7·95	−·07		

* *Ap. J.*, vol. 17, No. 201 (1903); *A.N.* 4005, 167, 347 (1905), and *A.N.* 4128, 172, 387 (1906).